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FORWARD AND BACKWARD DEUTERON PHOTO- DISINTEGRATION CROSS SECTION AND A TAGGED PHOTON BEAM FROM BREMSSTRAHLUNG ON AN ARGON JET TARGET

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FORWARD AND BACKWARD DEUTERON PHOTODISINTEGRATION CROSS SECTION AND A TAGGED PHOTON BEAM FROM BREMSSTRAHLUNG ON AN ARGON JET TARGET*

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Abstract.

The cross section for the photodisintegration of the deuteron was measured simultaneously at 0°, 90° and 180° c.m. angles for the outgoing protons and at 220 MeV lab photon energy. A quasi-monochromatic photon beam, obtained by positron annihilation on a liquid hydrogen target, was used and the photon spectrum measured on-line by a pair spectrometer.The experimental apparatus consisted of a liquid deuterium target, a magnet sistem and three E-ΔE telescopes. The results agree with a recent fit to all modern experimental data.

A proposed monochromatic photon beam produced by the tagging technique is described. The radiator is a condensed molecular beam of argon installed in a straight section of the Adone storage ring. The recoil electron counters are placed in the magnetic field of the next dipole ring.

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* presented by E. De Sanctis

1. - Forward and backward deuteron photodisintegration cross section

The deuteron photodisintegration reaction, $^2H(\gamma, p)n$, is one of the most fundamental of the few-nucleon reactions and, therefore, it has been fairly extensively studied, both by experimentalists and theoretists. Nevertheless, in spite of the considerable effort spent so far on these studies, the knowledge of the cross section of the process is still unsatisfactory.

This is in particular true in the energy region between the pion emission threshold and the $\Delta(1232)$ resonance, where the spread of experimental values covers a factor of 2 in the absolute normalization, well outside the quoted error limits. Most of the observed disagreements should probably be ascribed to the use of continuous bremsstrahlung photon beams.

Recently the development of new techniques for producing monochromatic photon beam and of advanced computational capabilities has pushed the $^2H(\gamma,p)n$ reaction into the forefront of renewed experimental and theoretical interest.

In Fig. 1 are summarized the result of the most recent experiments all performed using monochromatic photons; specifically the experiment with photons produced by inverse Compton scattering by M. P. De Pascale et al. (1), for E_γ= 15-75 MeV; the positron annihilation photon beam measurement by E. De Sanctis et al. (2), for E_γ= 100-255 MeV, and the tagged photon studies by J. Arends et al. (3), and by K. Baba et al. (4), respectively for E_γ= 200-400 MeV and 180-600 MeV.

In the figure the cross section of the process has been expressed according to the usual Legendre polynomial expansion

$$\left(\frac{d\sigma}{d\Omega}\right)_{c.m.} = \sum_{L=0}^{3} A_L(E_\gamma)\, P_L(\cos\theta),$$

where θ is the angle between the incoming photon and outgoing proton momentum, and the $A_L(E_\gamma)$ coefficients, up to $L= 3$, has been fitted, for each photon energy E_γ, to the angular distributions provided by the above quoted experiments. As show in Fig. 1, the experimental situation appears considerably improved in the last years towards a fairly consistent set of experimental data with accuracy levels of the order of ±5% on the differential cross section values. Moreover it must be mentioned that there is also agreement with recent measurements of the inverse reaction(5,6), and consequently now a reasonable basis of experimental values is provided for comparison with the theory.

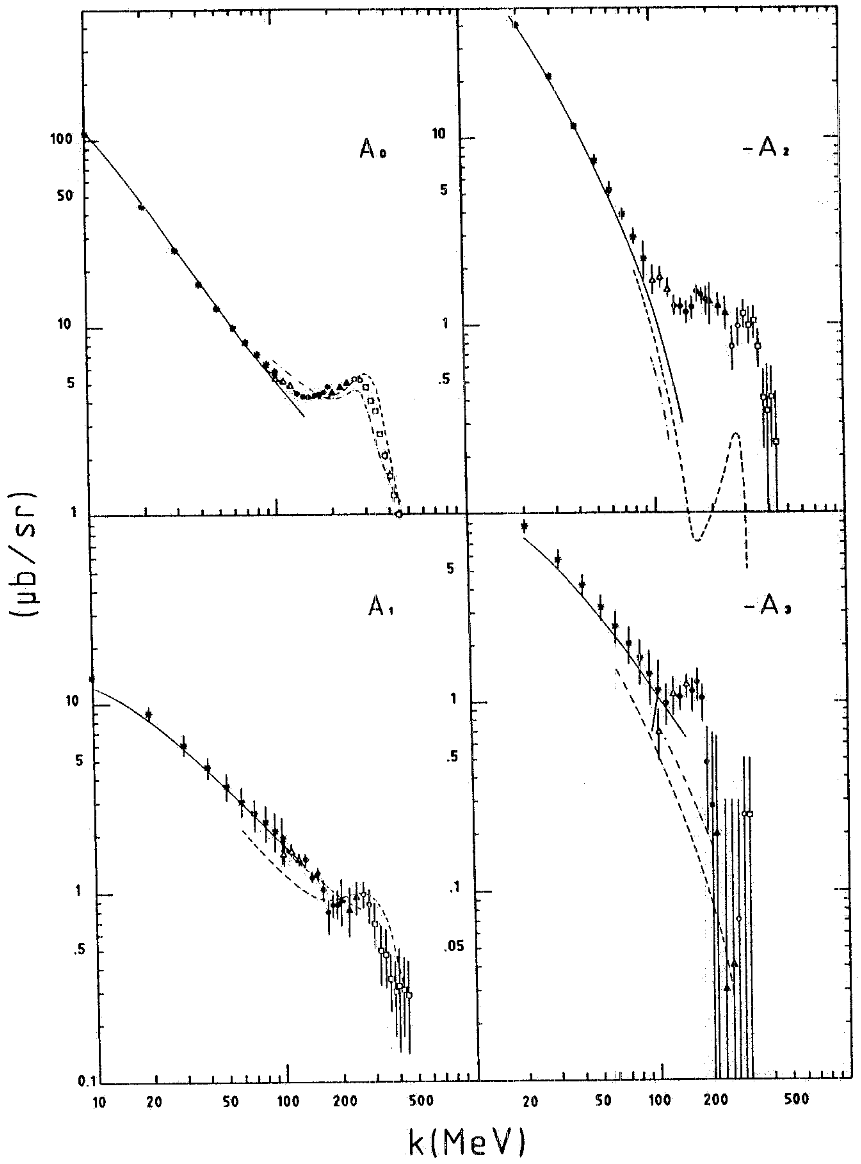

FIG. 1 - Obtained results for the Legendre coefficients A_i (i= 0,.., 3) as a function of photon energy: asterisks, data from Ref. 1; open triangles, data from Refs. 2 , 9 and 5 (only at k= 100 MeV); solid circles data from Ref. 2 only; solid triangles, data from Refs. 2 and 3; open circles, data from Ref. 3 only; open squares, data from Refs. 3 and 4; dashed, dotted-dashed, and solid lines are from Refs. 7, 8 and 9, respectively.

Fig. 1 also shows the values of the A_L coefficients deduced by fitting recent theoretical angular distribution calculations. The dashed curve is a calculation by Laget(7) performed using an expansion of the photodisintegration amplitude in terms of dominant diagrams; the dotted-dashed curve is a recent coupled channel calculation by Leidemann and Arenhövel(8), the solid line curve is a calculation by Cambi, Mosconi and Ricci(9) including second order relativistic corrections to the charge density. Despite the different theoretical approaches the results are qualitatively similar: the integrated cross section $4\pi A_0$, as well as the interference coefficients A_1 and (considering the error bars) A_3 are reasonably well reproduced, while $-A_2$ is strongly underestimated at energies greater than 100 MeV. Since A_2 determines the curvature of the angular distribution around 90°, the experimental data indicate that, above 100 MeV, the angular distributions are less isotropic than predicted by the theory.

We may therefore conclude that a better understanding of the two-body deuteron photodisintegration, at least above π production threshold, has still to be achieved.

From the theoretical side we may expect that the inclusion of ultrarelativistic corrections and/or a weaker tensor term, which already improved the agreement at forward angles below 140 MeV, may also reduce the observed discrepancy in the Δ excitation region.

From the experimental side one should provide a more complete set of data with the inclusion of the cross section values at the extreme angles . In order to accomplish this goal at Frascati it is presently going on a new measurement of the process in the photon energy range 100-260 MeV detecting simultaneously the protons ejected at 0°,90° and 180°. Therefore it will be possible to determine the forward to backward ratio of the cross section with reduced systematic errors and to check the absolute values by means of the 90° detector.

The measurements are carried out using the LEALE quasi-monochromatic photon beam produced by in-flight positron annihilation(11) on a liquid hydrogen target. A rectangular flat pole C-type magnet is used as an on-line pair spectrometer and the integrated photon flux on the deuterium target is measured by a gaussian quantameter.

The experimental apparatus is different from that we used in our previous experiment(2): protons ejected from the target are deflected by a magnet, cylindrical in shape (120 cm diameter, 20 cm gap) having a central hole (Φ =48 cm) where the deuterium target can be inserted. The target consists of a vertical mylar cylinder (40 mm diameter, wall thickness 0.08 mm) , filled with liquid deuterium. Three E, ΔE telescopes, positioned respectively at 0°, 90° and 180°, measure the proton energy spectra. The apparatus was installed and tested.

Recently collected data at 220 MeV photon energy were preliminarly analysed. The 90° cross section value is in excellent agreement with our previous one(2), the 0° and 180° cross section values result very close to those given by the Thorlacius and Fearing(12) fit to all more modern data (data group I in ref. 12).

2. - A tagged photon beam from bremsstrahlung on an Argon jet-target

In view of the great interest in nuclear physics studies with electromagnetically interacting probes, at Frascati it is foreseen to install an internal jet target on the electron storage ring Adone for producing a monochromatic high energy (up to 1200 MeV) photon beam through the tagging technique.

The use of internal targets in circulating beams antedates the availability of external beams from circular machines. In recent years, with improved understanding of beam dinamics and the construction of high energy synchrotron and storage rings, there have been a renewed interests in this option and growing activity in the development of suitable targets. The target which gives the largest luminosity is a type of condensed molecular beam(13) which provides a flow of gas at supersonic speed (hence the name of gas "jet" target) due to the expansion of gas from a vessel at high pressure and low temperature into the vacuum through an injector of very small aperture (10÷150 μm) and special geometry. The molecular jet flies forward along the axis of expansion and it is absorbed after having traversed the accelerator vacuum pipe. Only the core of the jet reaches the ultra-high vacuum of the ring via differential pumping stages where pratically all the uncondensed residual gas is pumped off.

Fig. 2 shows the schematic view of the jet target proposed for Adone. The Argon jet is produced in the chamber 1 (installed on top the Adone vacuum pipe) where the gas expansion takes place. The injector is a converging-diverging nozzle with special trumpet-shaped end part. Then the jet move across the machine vacuum pipe to the sink system, installed below the ring.

We have interposed three differential pumping stages (each equipped with a 350 l/sec turbo-pump) to separate both the expansion and the sink chambers from the vacuum pipe in order to minimize the pressure rise in the interaction region ($\leq 10^{-8}$ torr). An additional pumping system (two 1000 l/sec turbo-pumps) is acting on the straight section of the ring where the jet target will be mounted, in order to reduce this rise pressure and limit the length of the region where the pressure is $\approx 10^{-8}$ torr. Two fast acting UHV valves separate the production and sink chambers from the Adone vacuum pipe to easy the jet on/off operations and to prevent the possible contamination of the ring in case of a large pressure bump due to breakdown of the target system.

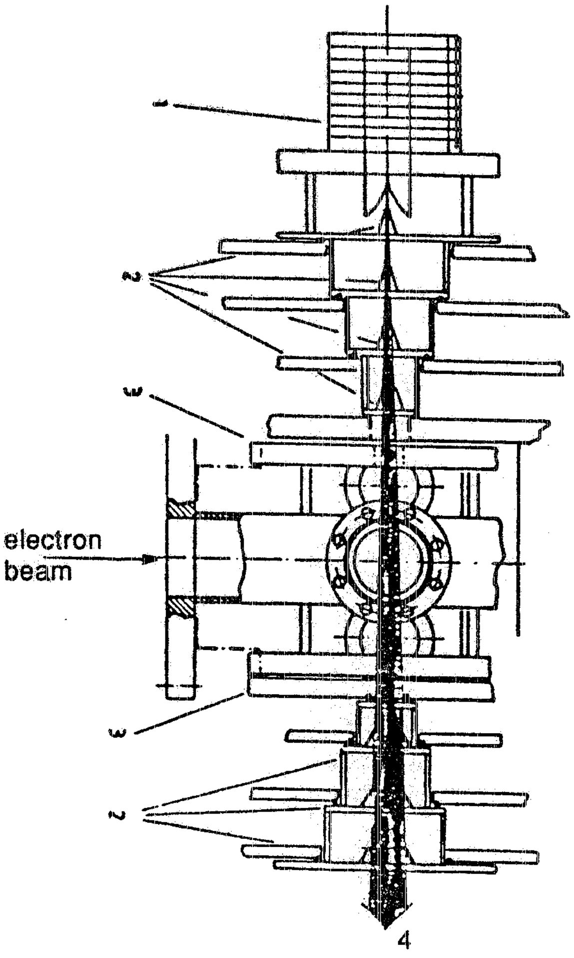

FIG. 2 - Side view of the Argon jet target proposed for Adone: 1 gas expansion chamber; 2 collimators; 3 valves; 4 sink chamber.

The operating conditions are inlet pressure and temperature 6 bar and 150 °K, respectively, nozzle throat diameter 87 μm and semiaperture 3.5°. From a total flux of $\approx 10^{20}$ Ar- atoms/sec expanding from the nozzle the collimator system selects $\approx 5\ 10^{18}$ atoms/sec, which corresponds to a target thickness of $\approx 10^{-8}$ g/cm^2 (Φ=1cm) on the path of the electron beam (that is at a distance of $\approx$25 cm from the nozzle).

The circumference of the Adone ring is approximately 105 m, so that a bunch of ultrarelativistic electrons takes about T_0 =351 nsec to make a round. The ring is divided in twelve identical lattice elements each consisting of a (n=1/2) bending magnet with a quadrupole doublet on each side.

Electrons are injected into the storage ring at an energy of 300 MeV (a few-turn injection will result in about 100 mA current circulating in the ring) and then accelerated to the desired energy by rising the magnetic field of the guiding magnets (this operation requires about 20 sec). The 51.4 MHz RF-cavity groups the circulating electrons into 18 buches, each $\approx$1nsec wide and $\approx$20 nsec apart.

After the rise in energy the Argon jet will be fired into the vacuum pipe and the electron beam lifetime $\tau = T_0/(\sigma_\varepsilon x)$ cut down to about 130 sec (T_0 is the revolution period, σ_ε the removal cross section and x the jet target thickness). Then the cycle is ended by lowering the field of the magnets to the injection value. The removal cross section involves only the process of bremsstrahlung in which the electron loses sufficient energy to place it outside the acceptance band-width of the ring (ε= 0.01E_0, E_0 being the machine energy). In fact the target thickness is so small that neither the multiple scattering nor the ionization losses contribute to the lifetime, being the RF- cavity able to compensate for both the growth in divergency and the mean energy losses.

In Fig. 3 is sketched a lay-out of the apparatus: the Argon jet will be placed in a straight section (2.58 m long) between consecutive lattice elements and the recoil electrons will be momentum analyzed by the next dipole magnet and detected by a two-array scintillation counter hodoscope. This hodoscope will be placed between the ring vacuum pipe and the dipole magnet flux return joke. The scintillators have various sizes to give equal photon energy resolution ($\approx$1% at E_0=1500 MeV) over the whole tagging range. The complete tagging system defines 80 energy channels covering the photon energy range k= (0.4÷08) E_0. This implies an extensive array of tagger detectors covering a side about 1m long of the bending magnet pole.

Since the determination of the photon energy relies on a coincidence between the tagging counters and the detector for the photoejected particles, the tagging method is subject to usual limitation due to random coincidences. In the normal operating mode the facility produces $\approx 10^8$ photons/sec in the whole tagging range. To make the operation of the tagged photon beam possible at the maximum intensity it is foreseen the installation of a new 350 MHz RF-cavity which makes the beam almost continuous in time (126 bunches 2.86 nsec apart).

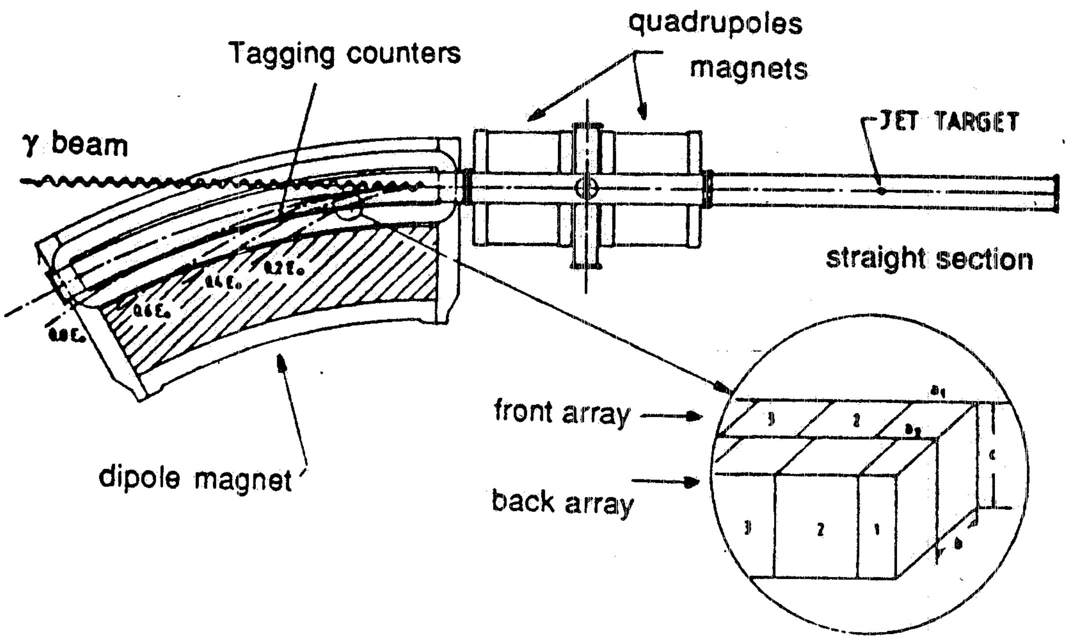

FIG. 3 - Schematic view of the tagging system.

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